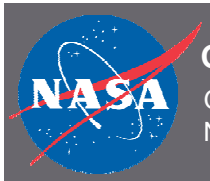


Global Modeling and Assimilation Office
Goddard Space Flight Center
National Aeronautics and Space Administration

The Simulation and Assimilation of Doppler Wind Lidar Observations in Support of Future Instruments

Will McCarty
NASA/Goddard Space Flight Center
Global Modeling and Assimilation Office

R. Errico, R. Yang, M. McGill, S. Palm, R. Gelaro, M. Rienecker

GMAO Internal Seminar

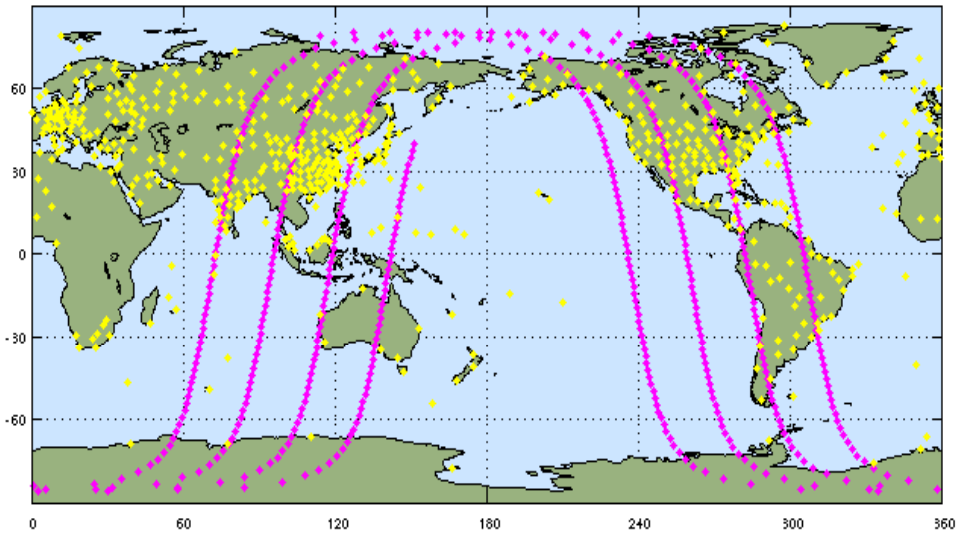
Introduction

- Importance of Wind Measurements
  - Global wind profiles are “essential for operational weather forecasting on all scales and at all latitudes”
    - World Meteorological Organization (1996)
- Atmospheric Winds from the ground
  - Global Rawinsonde Record
  - Ground-based, remotely sensed wind observations
  - Mainly in data rich regions
- Atmospheric Winds from Space
  - Atmospheric Motion Vectors (AMVs) and Scatterometers

w1

Introduction to Doppler Wind Lidar

- The Doppler Wind Lidar Concept
  - Lidar backscatter is Doppler shifted by a scattering agent
  - Improved accuracy in height assignment
- Spaceborne Doppler Wind Lidar
  - Global, 3D measurements of wind
  - NASA **3D-Winds** (NRC Decadal Survey recommendation)
    - Full horizontal wind
  - ESA **ADM-Aeolus** (2012)
    - single horizontal wind component



Radiosonde | ADM

Observation Locations

Slide 3

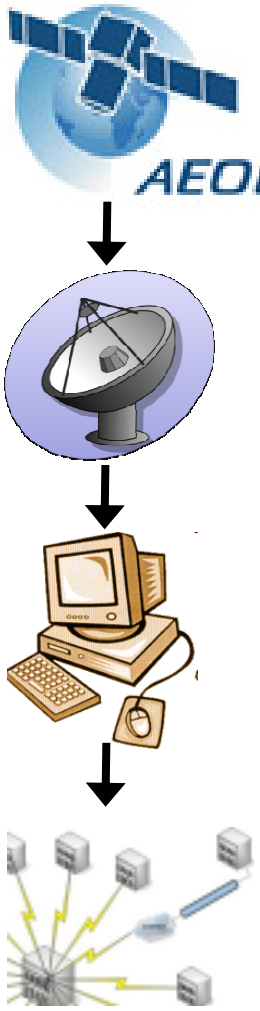
w1 wrmccart, 4/30/2010

ADM-Aeolus

- Direct-Detection technique (355 nm)
  - Vertical single-component profiles in clear sky (Rayleigh)
  - Higher quality measurements in presence of scattering agent (Mie)
- Orbit Characteristics
  - 408 km
  - Dawn-dusk
  - Sun-synchronous

- Viewing Geometry/Sampling
  - 90° off-track (away from sun)
  - 7 second measurements (~50 km)
  - One measurement every 200 km

ADM-Aeolus Pre-Assimilation Data Flow Chart



- Downlink
  - Location: Svalbard
  - Latency
    - Near-Realtime: 3 hr
    - Quasi-Realtime: 30 min
- Processing & Distribution
  - L1B distributed in NRT by ESA via GTS
  - L2B product will be produced by ECMWF (IFS)
    - NRT modeling centers will have to run L2B processing independently
      - Best scientific methodology due to first-guess dependency

ADM-Aeolus Pre-Launch Data Flow Chart

- Prior to launch, realistic data for system preparedness
  - Establish a realistic dataset for data assimilation system development
    - Local Proxy Data
    - Generated using OSSE framework
      - Purpose of this effort is not to “sell” instrument (already sold)
  - Establish a realistic end-to-end flow to test mechanics of system
    - NRT Proxy Data
    - To be considered closer to launch

Data Assimilation

- Variational Cost Function:

$$J(\mathbf{x}) = (\mathbf{x}-\mathbf{x}_b)^T \mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_b) + (\mathbf{y}-H[\mathbf{x}])^T \mathbf{R}^{-1}(\mathbf{y}-H[\mathbf{x}])$$

- When minimized,

$$\mathbf{x} = \mathbf{x}_a \text{ (analysis state)}$$

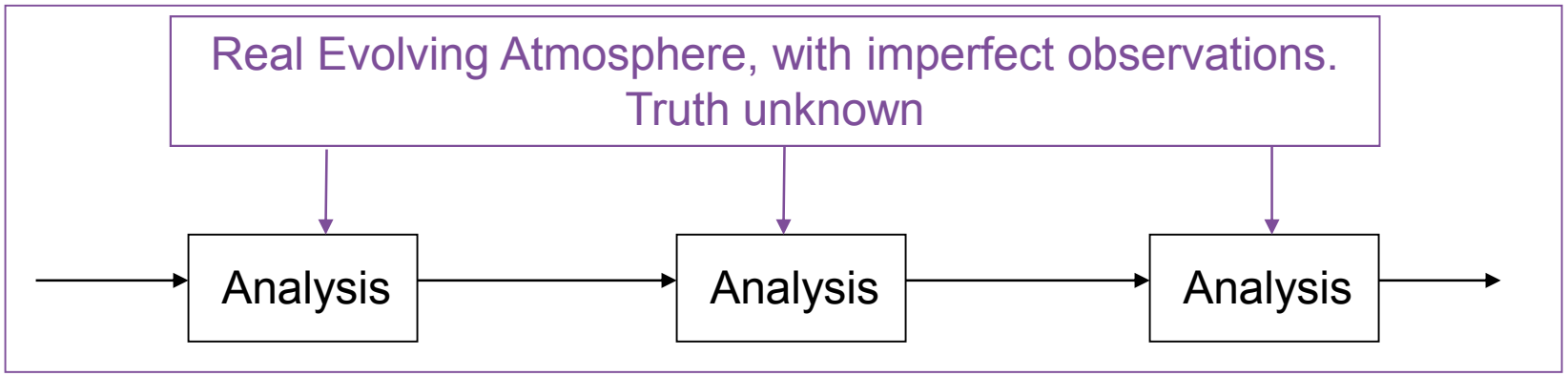
- $H[\mathbf{x}]$ transforms the atmospheric state to observation space
  - Currently, $H[\mathbf{x}]$ is a projection of the winds to line-of-sight space
  - Upon launch, $H[\mathbf{x}]$ will include L2B processing

OSSE for ADM Preparedness

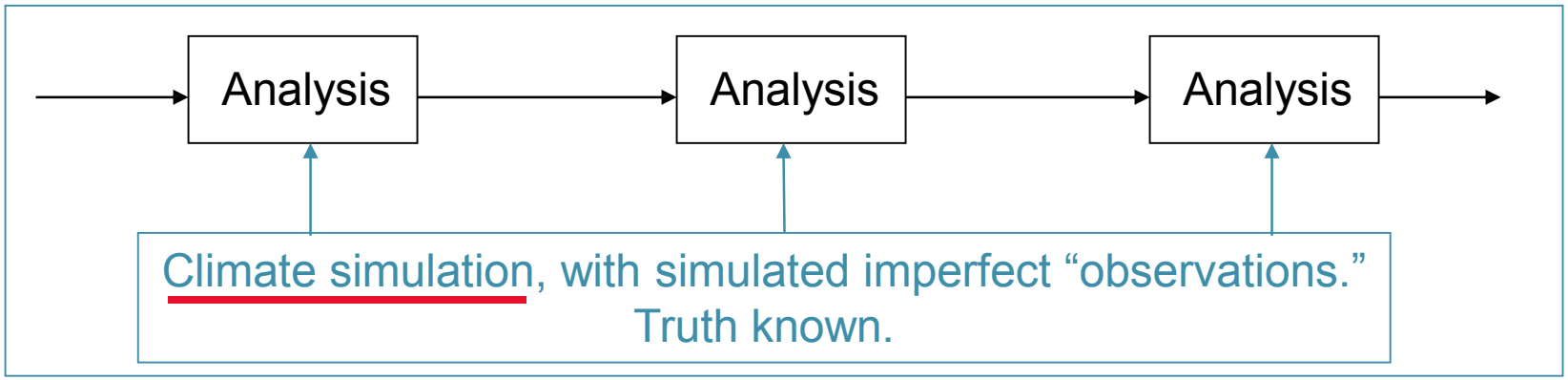
- There is no predecessor for spaceborne DWL
- Sources of proxy data
  - Ground-based instruments
    - Inadequate spatial sampling
  - Adapt existing spaceborne measurements
    - Completely different in nature than spaceborne DWL
  - Simulated Observations
    - Can be simulated anywhere
    - If done properly, they can contain all of the necessary characteristics to best emulate real data:
      - Spatial and vertical sampling
      - Yield
      - Error characteristics

What is an OSSE

Assimilation of Real Data



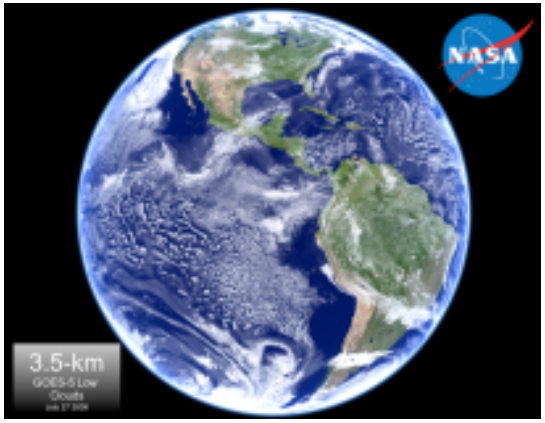
Time →



Observing System Simulation Experiment (OSSE) (R. Errico)

The "Real" Atmosphere

- In an OSSE, an atmospheric model is run in a climate (free-running) mode
  - This is the Nature Run (NR)
- The behavior of this atmosphere is essential to the process
  - Though artificial, it needs to be realistically chaotic
  - It is the truth

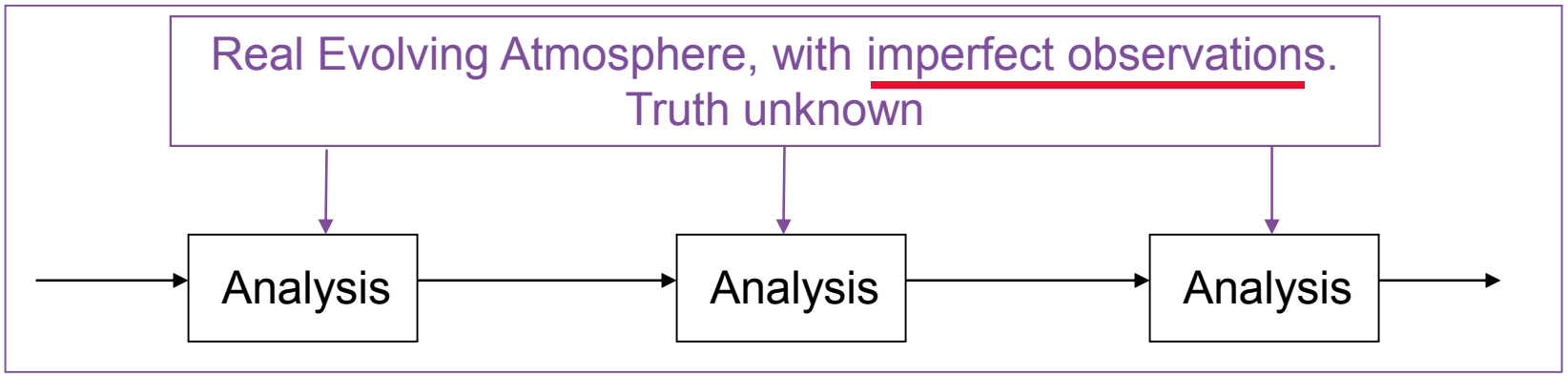


3.5 km GEOS-5 Climate Simulation

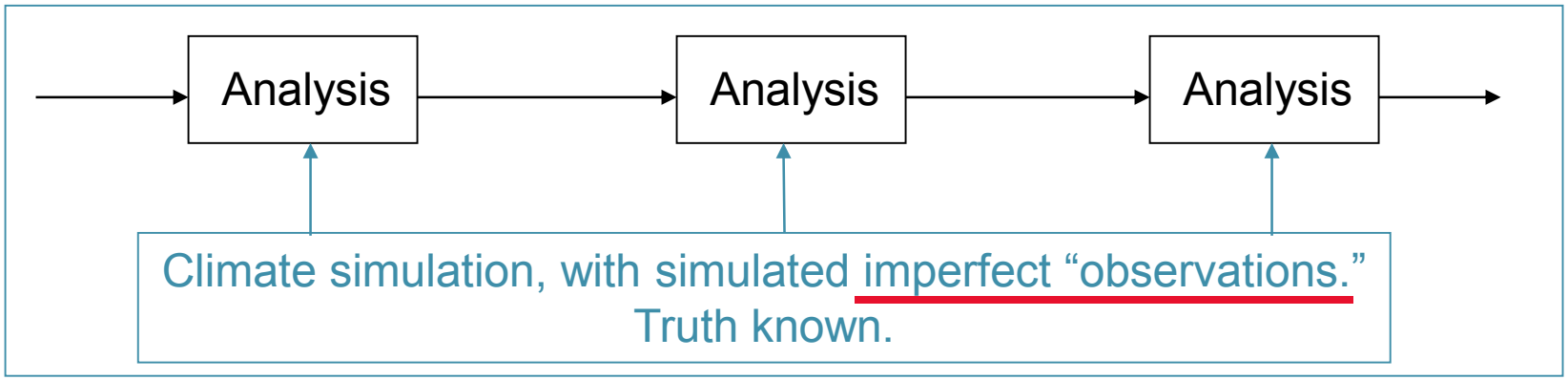
- Current Nature Run – Joint OSSE Nature Run
  - T511 ECMWF 13 month model run spawned in May 2005
- Future Nature Run – GMAO/GEOS-5 Hi-res Nature Run

What is an OSSE

Assimilation of Real Data

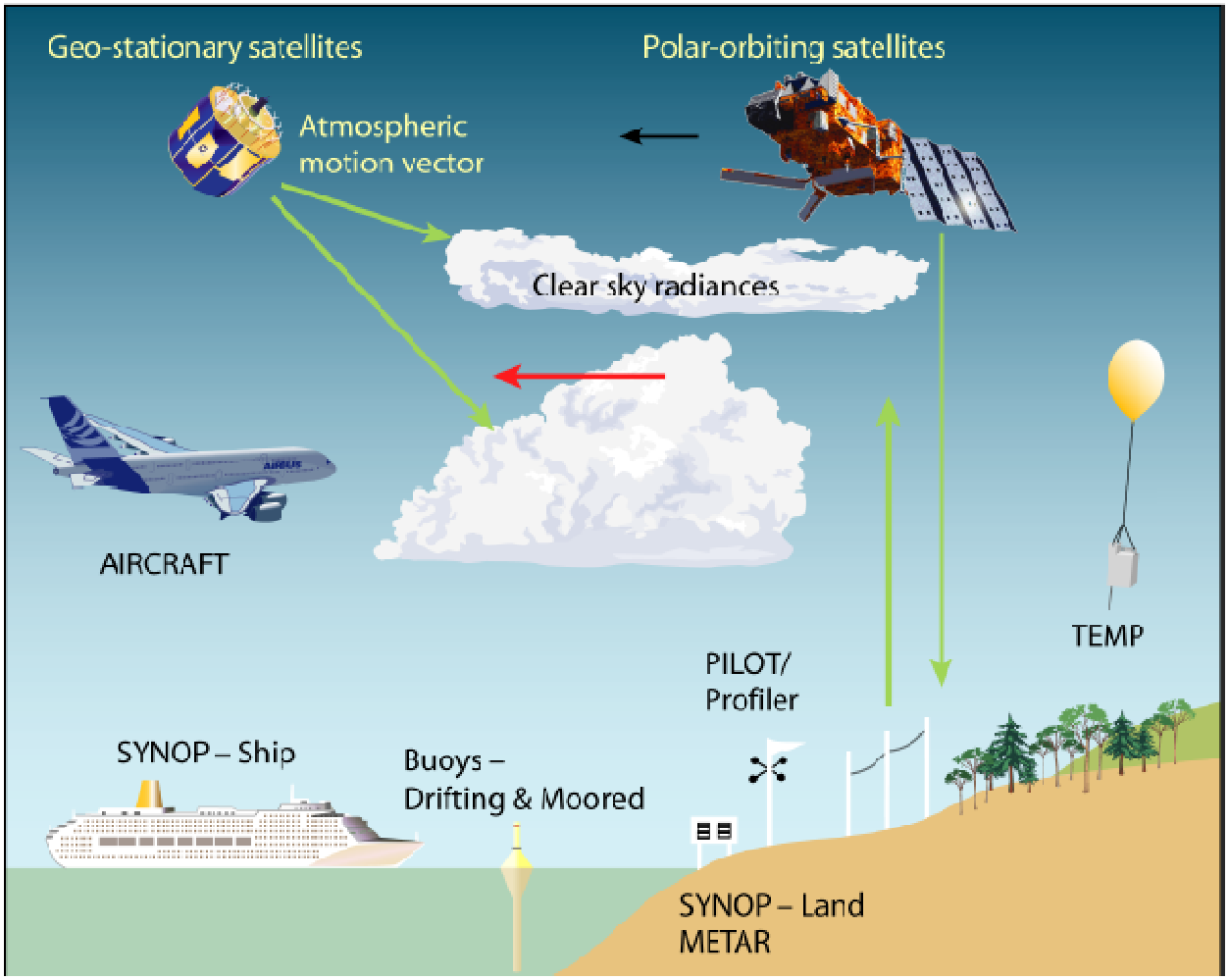


Time →



Observing System Simulation Experiment (OSSE) (R. Errico)

Simulating Observations



- Six million+ observations are assimilated globally, daily
  - Most observations are from satellites
- A successful OSSE requires realistic fake observations

Figure via ECMWF

Simulating a Realistic Observing System

- The analysis solution (minimized cost function) can be written as

$$\mathbf{x} = \mathbf{x_b} + \mathbf{K}\left[\mathbf{y} - H(\mathbf{x}_b)\right]$$

- In an OSSE, your observations are

$$\mathbf{y} = H_z(\mathbf{z}) + \mathbf{e}$$

- The validity of a simulated observation network is dependent on the errors
  - Simulated observation errors (**e**) need to account for
    - Instrument noise
    - Observation contamination (data yield, i.e. clouds, precipitation)
    - Representativeness (sub-gridscale variability)

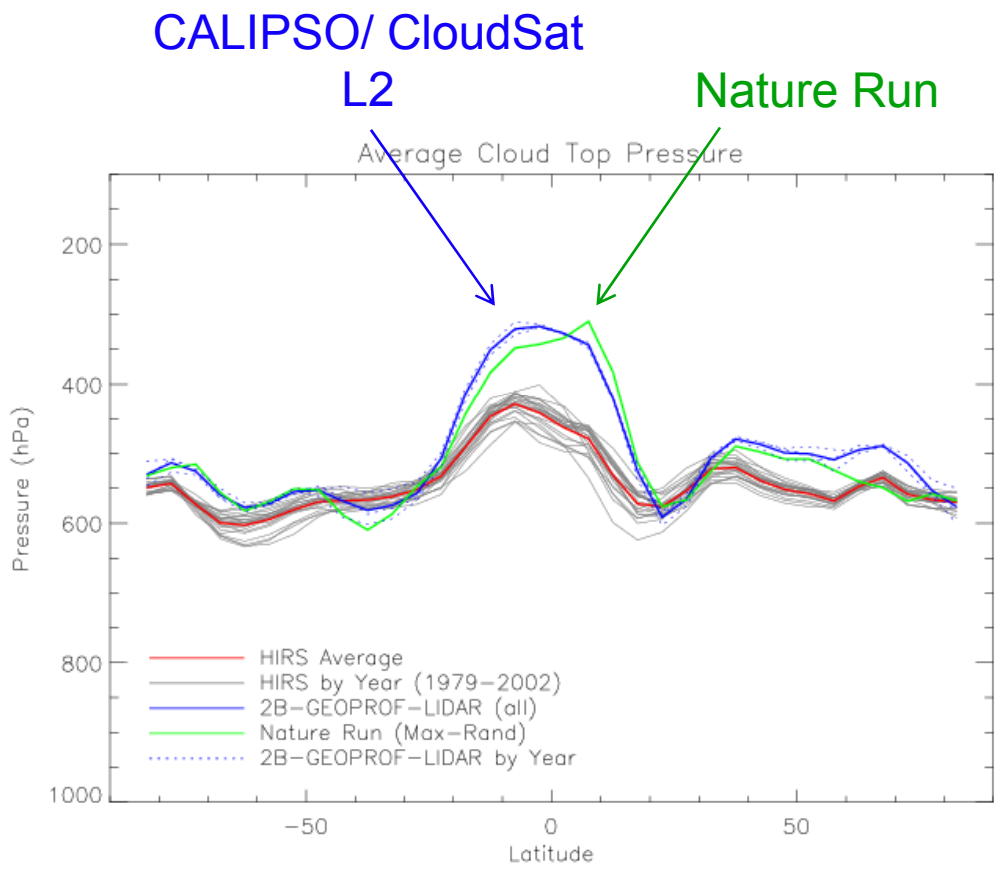
Simulating Doppler Wind Lidar Observations

- Simulation of ADM is dependent on key fields
  - Backscatter & extinction from the atmosphere, clouds, and aerosols
  - 3D wind field
- Only the wind field is inherent to the nature run
  - Molecular/Rayleigh backscatter – f(T,p)
  - Cloud backscatter/extinction – f(Cloud Fraction, CLWC, CIWC)
  - Aerosol backscatter/extinction
    - Not inherent to NR
- ADM measures at a scale finer than that of the NR
  - Need to account for sub-gridscale variability
- The DJF season of the NR is compared to the seasonally corresponding CloudSat/CALIPSO (CS/CAL) record

Comparing NR Clouds to CloudSat/CALIPSO

- Only cloud fraction is considered
- CS/CAL
  - Level 2B GEOPROF-LIDAR product
  - 1 km resolution along-track, reports up to five cloud layers
  - Only consider highest vertical cloud
- NR
  - A maximum-random overlap scheme implemented for sub-gridscale variability
    - Adjoining model levels to have maximum overlap
    - If two clouds exist in a vertical column with clear-sky between them, random overlap is assumed
    - Sampling the same as one season of the CS/CAL data
- Comparisons are made in 5° bins

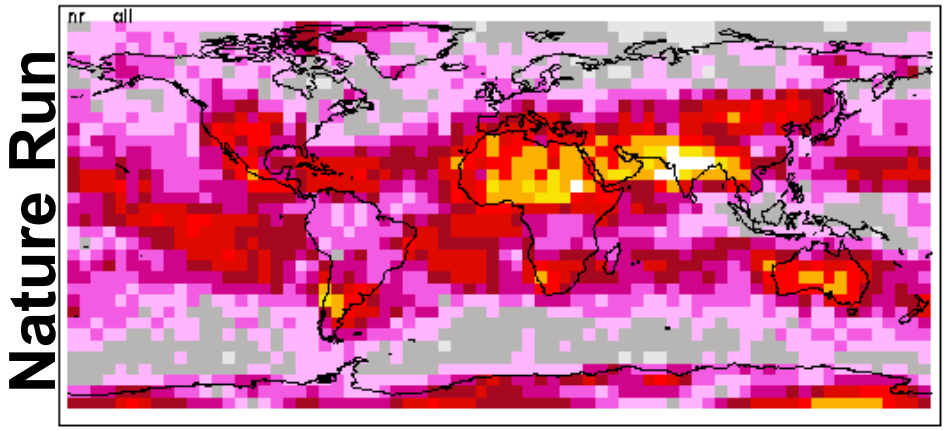
Clouds in the Joint OSSE Nature Run

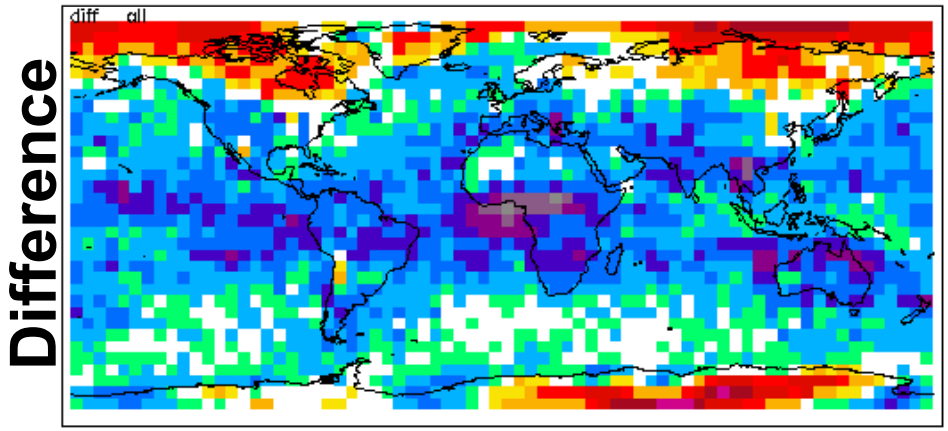


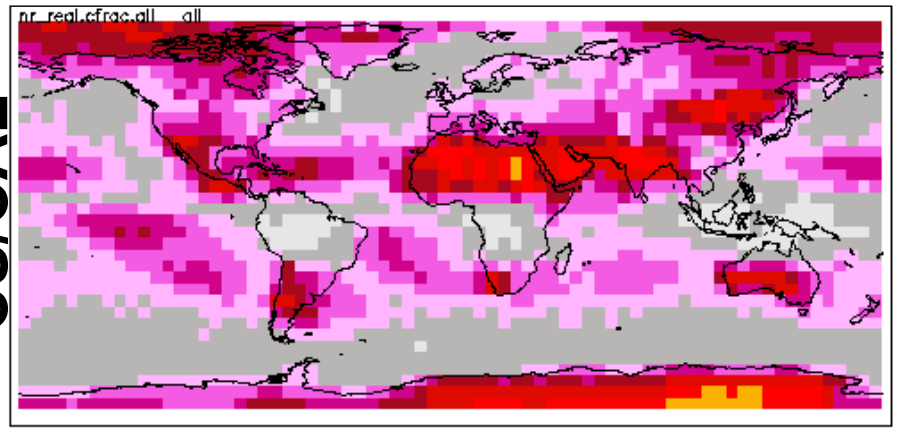
- Importance of clouds
  - The top of a cloud can act as a scattering agent
  - Optically thick clouds limit wind retrievals
- Placement of clouds
  - Realistic vertical placement of clouds
  - NR underestimates cloud amount
    - ~12% globally
    - Related to measurement yield

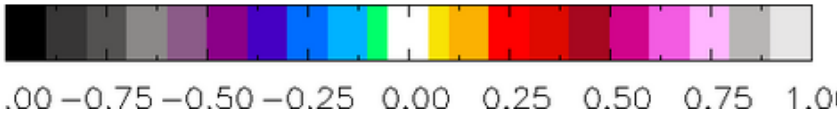
Clouds in the Joint OSSE Nature Run

- Cloud Fraction for all clouds
- Clear lack of clouds in NR









Aerosols in the Joint OSSE Nature Run

- Importance of aerosols
  - Aerosols act as a scattering agent
- Placement of aerosols
  - Not available in the NR
  - Traditionally taken from a climatological background
    - Inconsistent with atmospheric state
  - Dynamically consistent aerosol fields
    - Unique GSFC effort
    - GOCART aerosol transport model embedded in the GEOS-5 model
      - Aerosol fields forced by the meteorology of the Nature Run

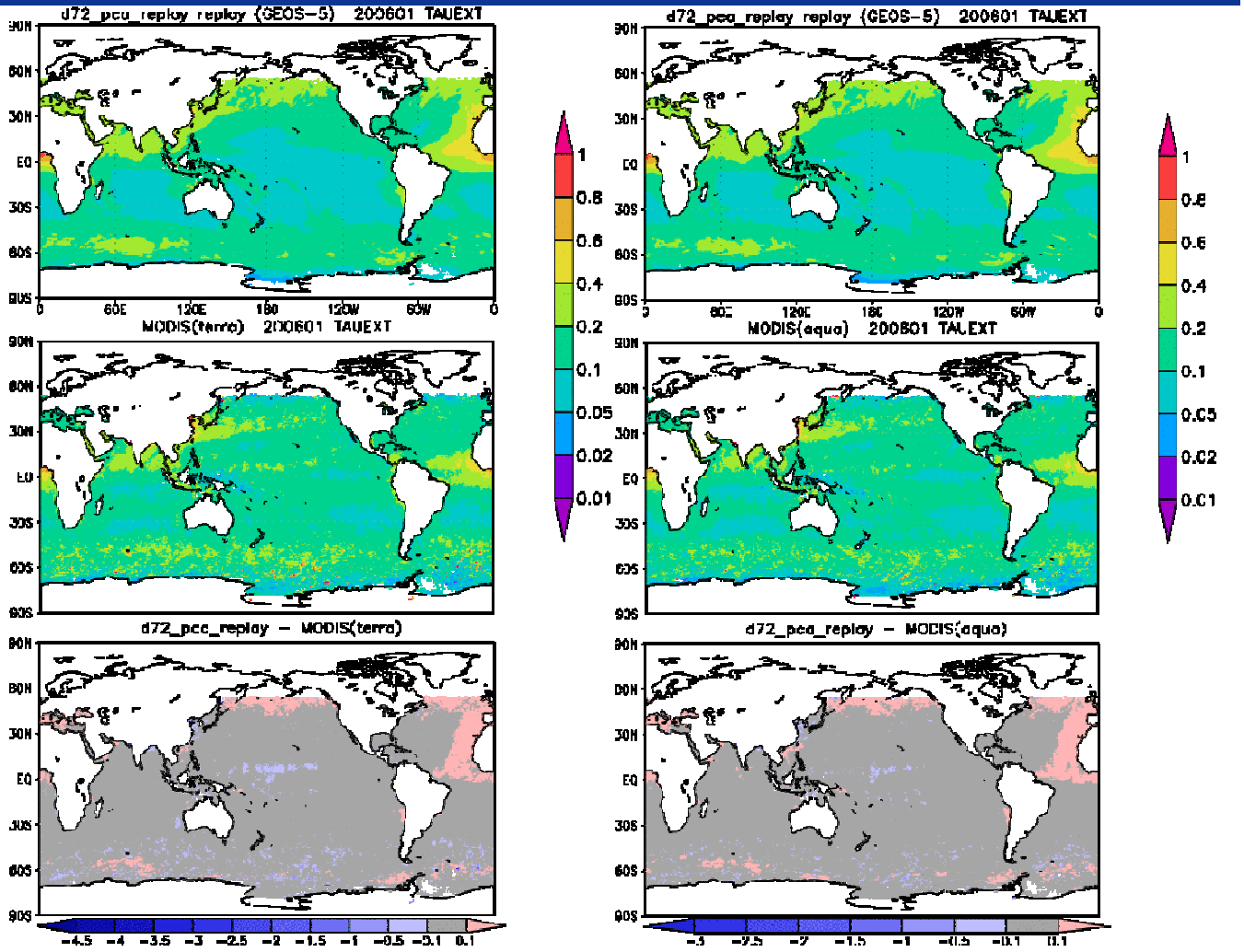
Aerosol Validation

- Replay aerosols compared to MODIS (Aqua and Terra, separately) and MISR
  - NR sampled at MODIS/MISR retrievals for consistency
    - Clear sky, daytime only
- Showing January of the Nature Run versus real January 2006

Aerosol Validation

- Terra (left)
- Aqua (right)

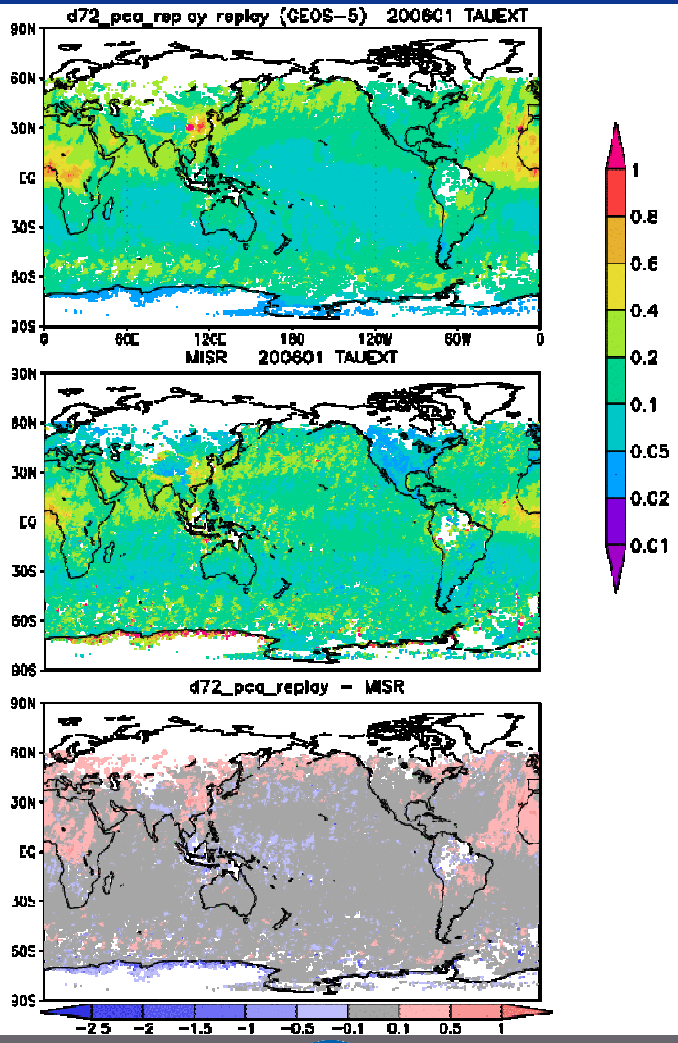
- NR (top)
- MODIS (middle)
- NR – MODIS (bottom)



(R. Govindaraju)

Aerosol Validation

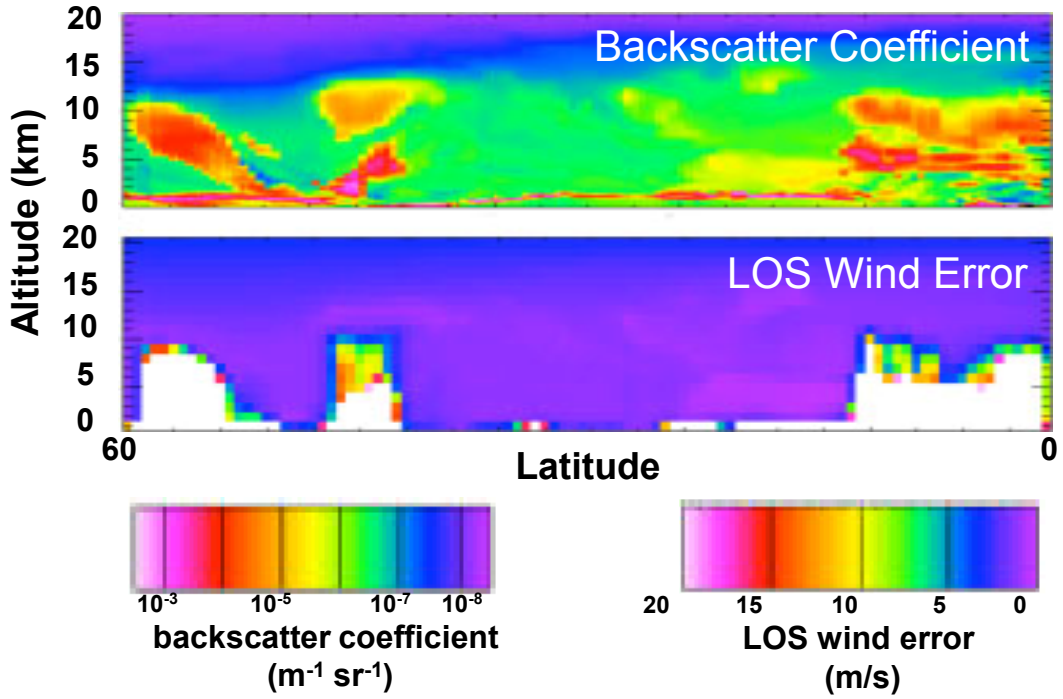
- NR (top)
- MISR(middle)
- NR – MISR (bottom)



(R. Govindaraju)

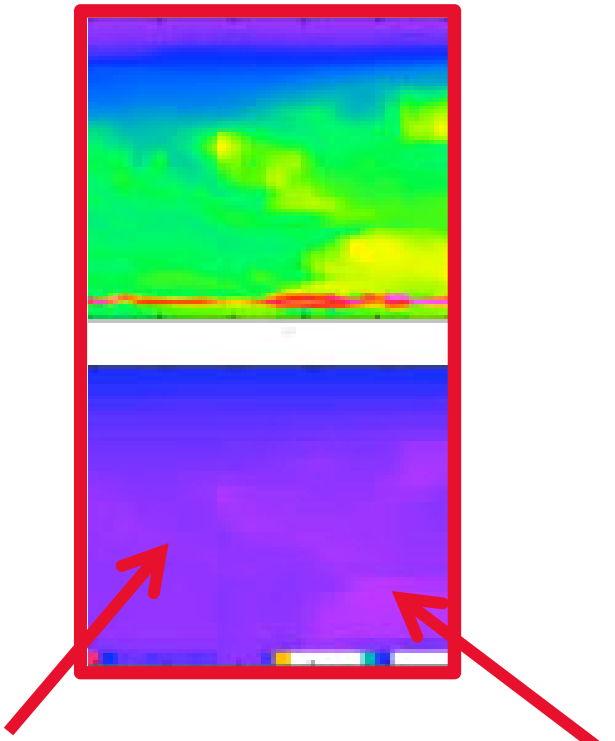
Simulated Doppler Wind Lidar Observations

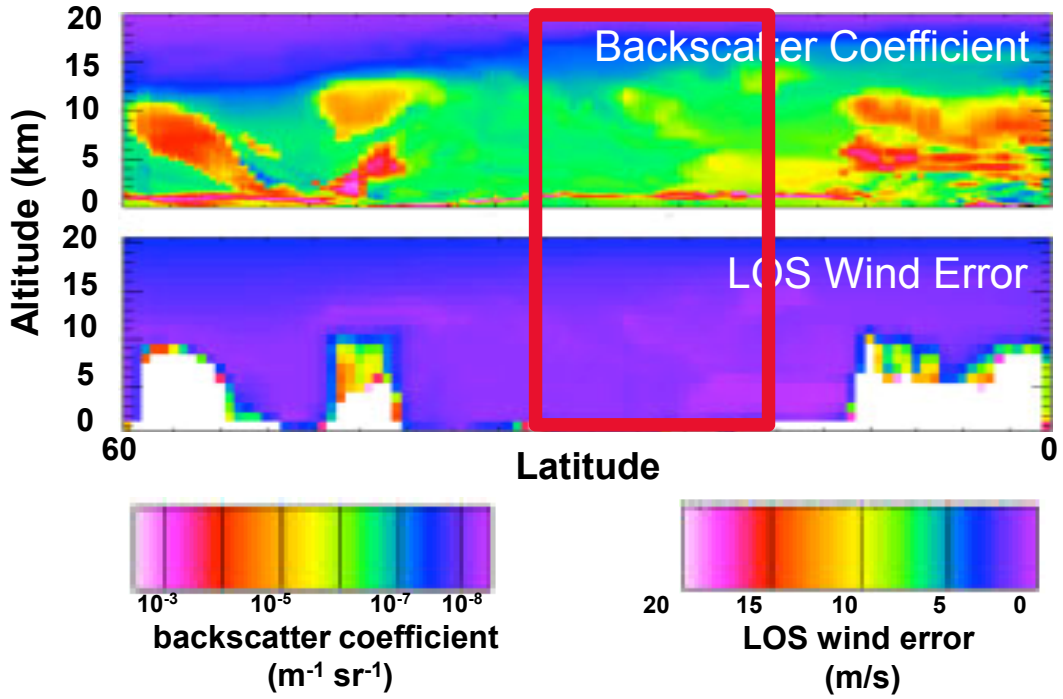
- Simulated from a modeled atmospheric state
- Errors increase with height
- Clear-Sky backscatter coefficient and line-of-sight wind error are inversely proportionate
- Clouds degrade measurement quality



(M. McGill, S. Palm)

Simulated Doppler Wind Lidar Observations



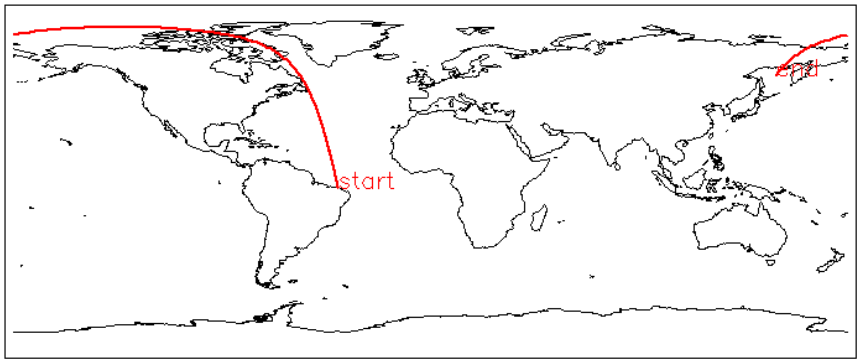


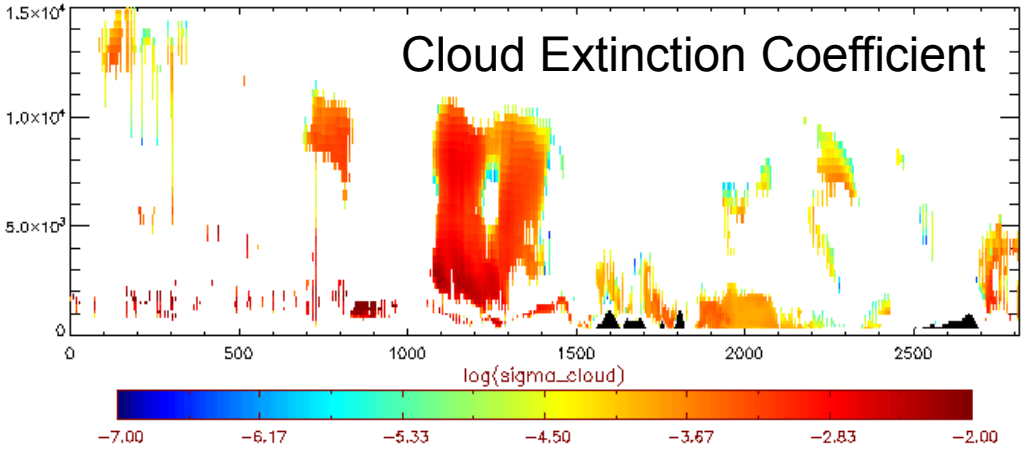
- Molecular detection full wind profiles vertically
- Aerosol detection has reduced error

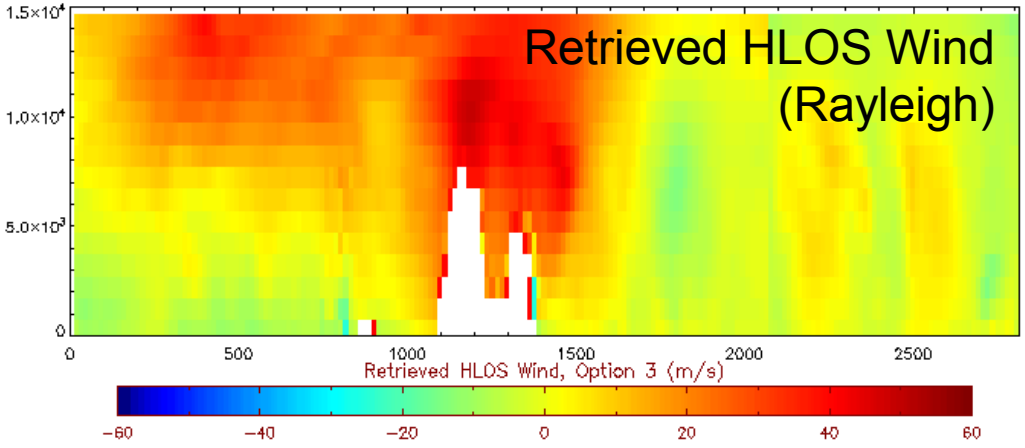
(M. McGill, S. Palm)

Simulated Doppler Wind Lidar Observations

- Simulated ADM measurements
  - Nature Run
  - LIPAS
    - ADM Simulator developed at KNMI
  - Not run in “Burst Mode”







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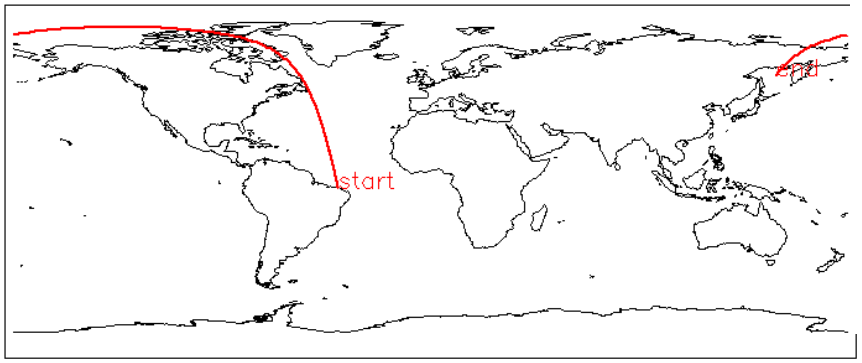

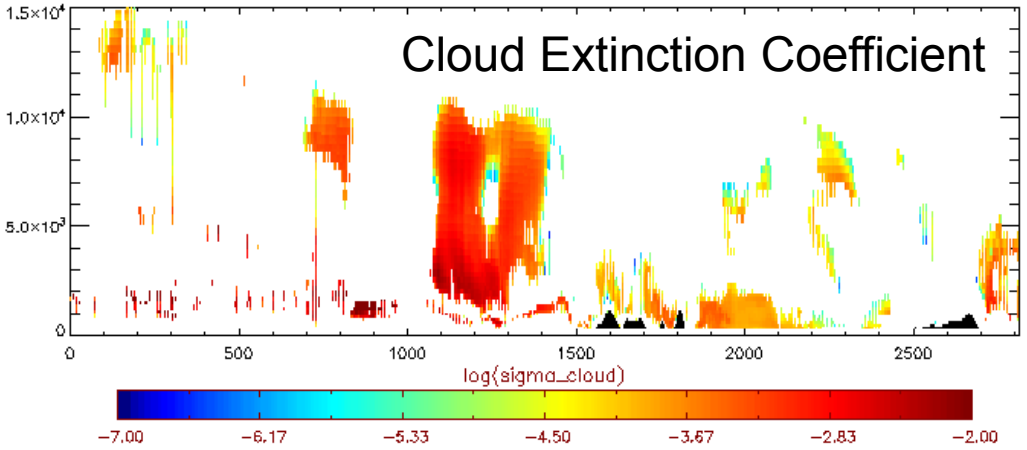

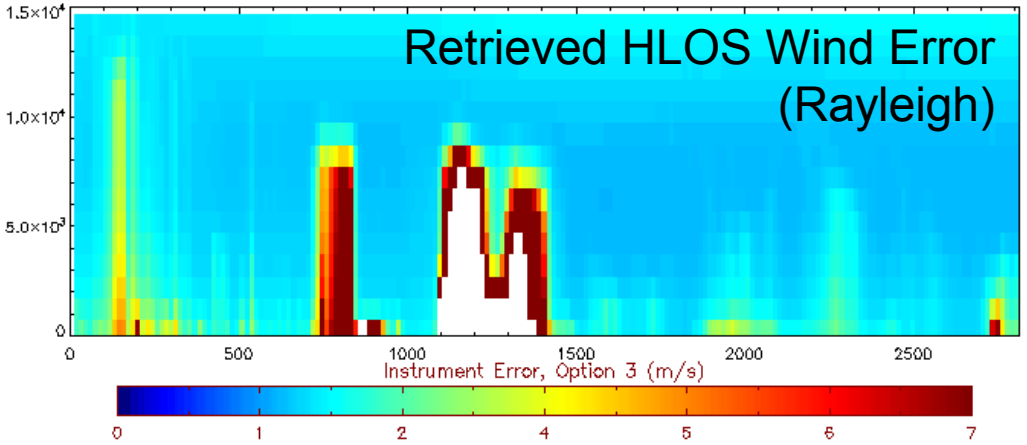

Simulated Doppler Wind Lidar Observations

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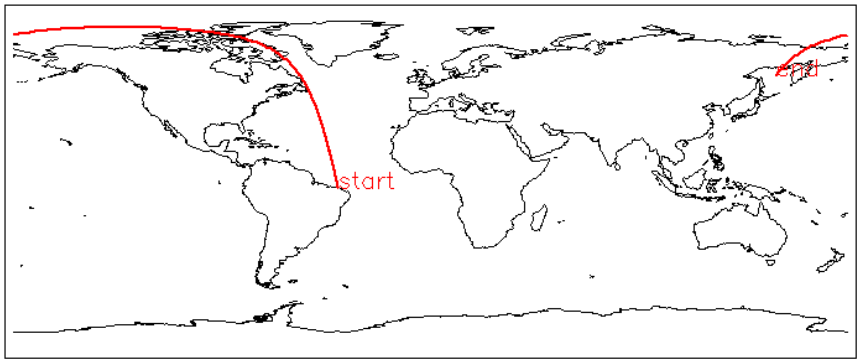
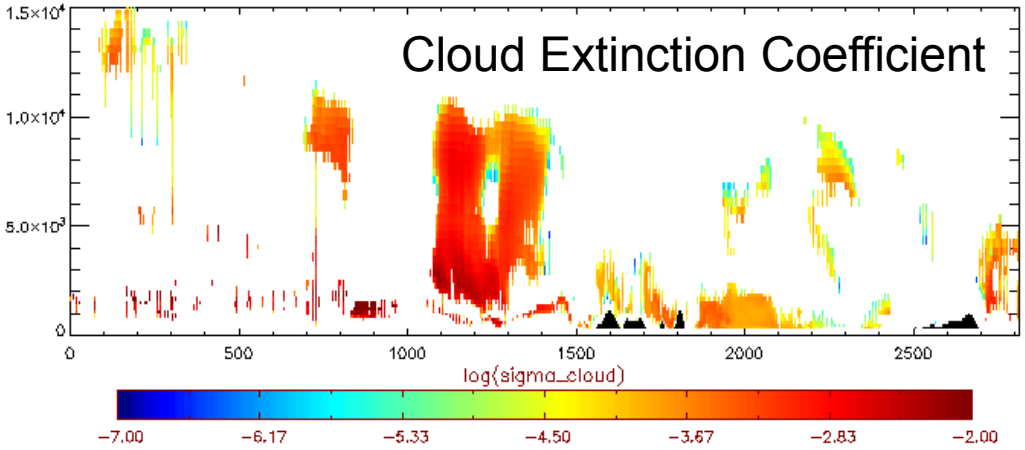
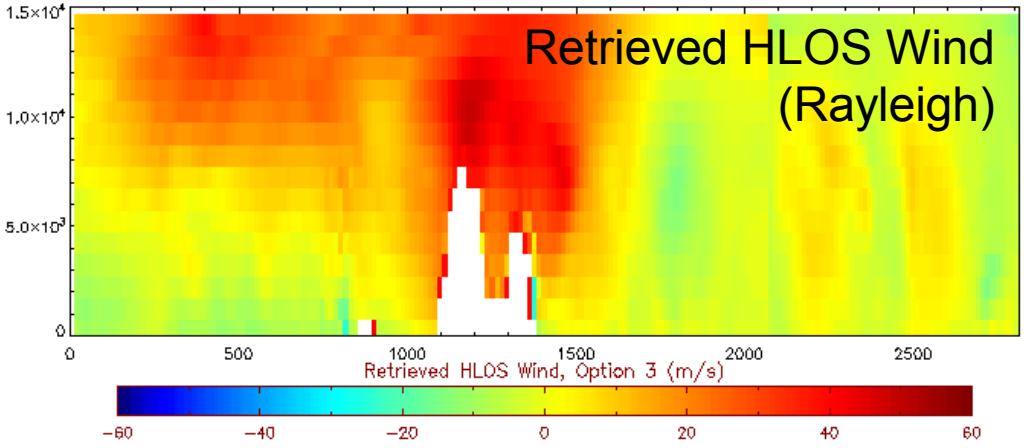
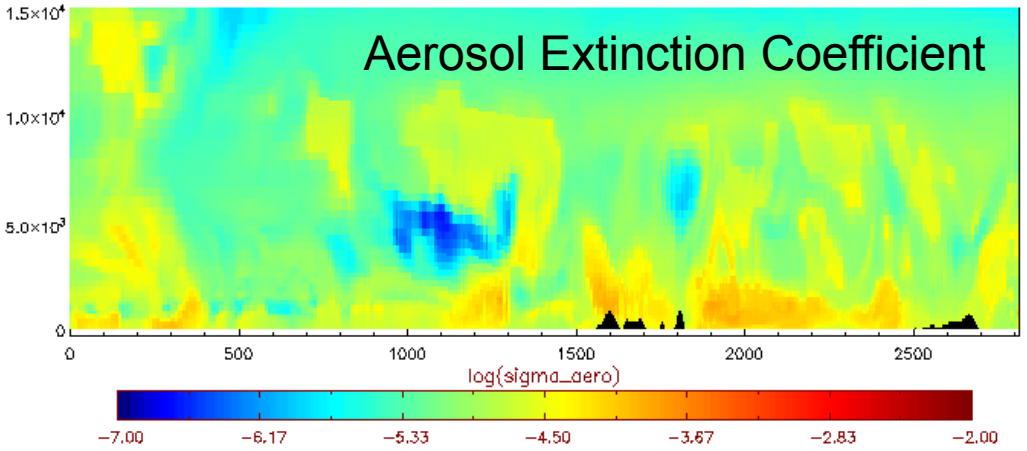


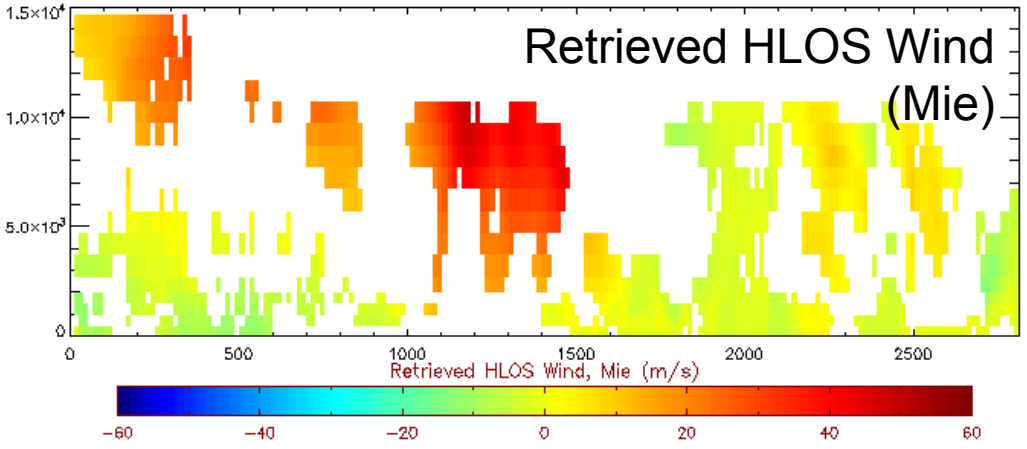


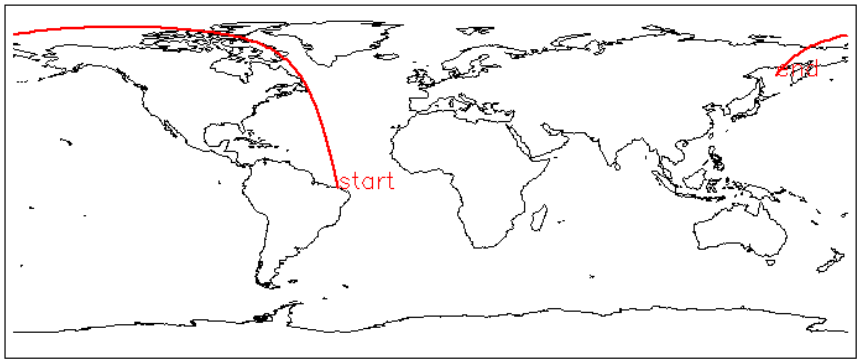


Simulated Doppler Wind Lidar Observations

- ADM Obs (cont'd)
  - cloud and aerosol fields consistent
  - Mie channel sampling illustrated





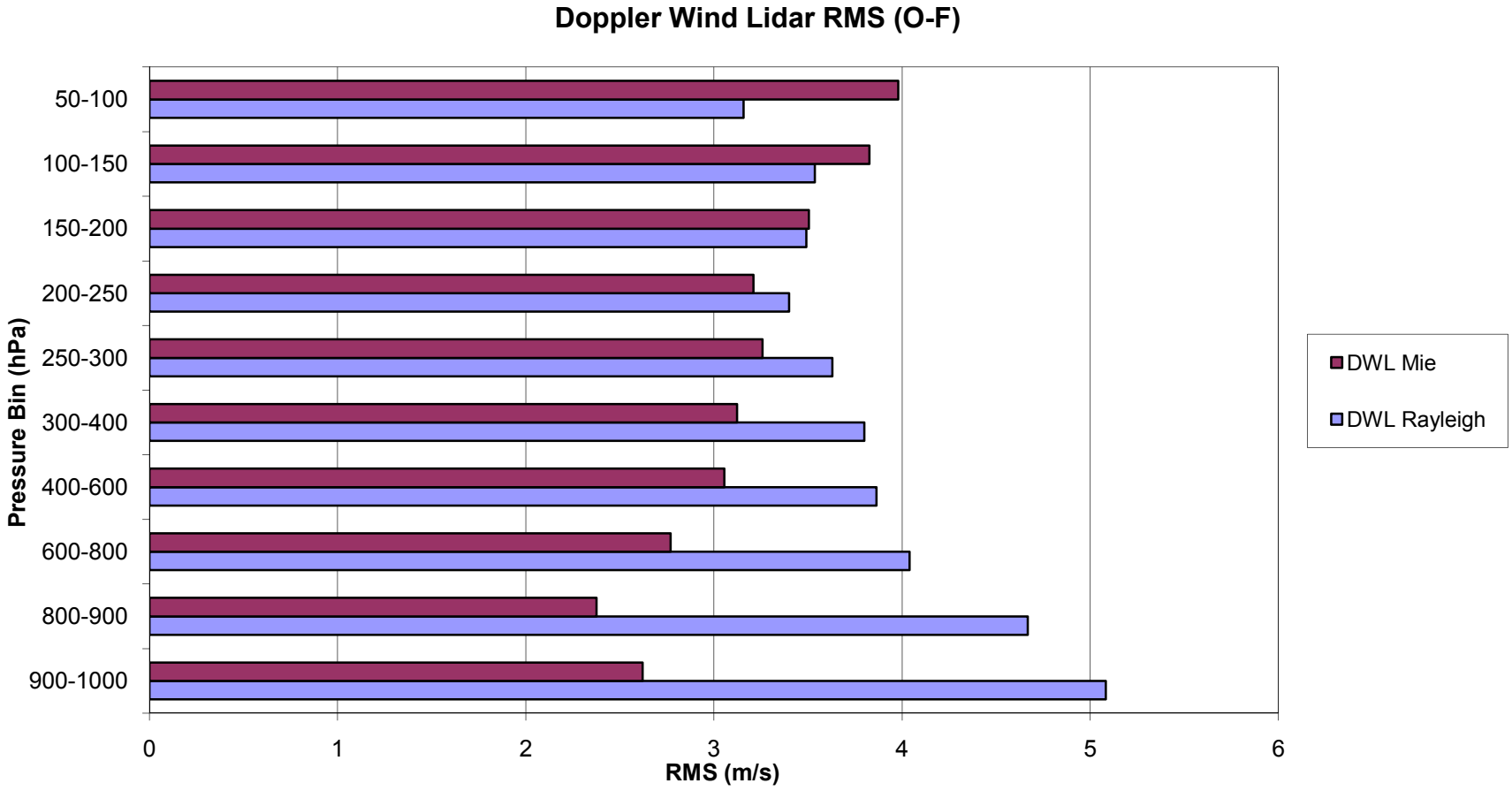


Assimilation and Forecast Impacts

- The results shown are applicable to January of the nature run period
  - DAS Runs every 6 hr with a +/- 3 hr observation window
- Analyses are considered 2x/day (00/12 UTC)
- Forecasts are considered 1x/day (00 UTC)
- Observations included in Control
  - Based on operational data for Jan. 2006
  - Conventional (incl. RAOB & Satellite Winds), TOVS (MSU, AMSU A/B, HIRS), AIRS
- Observations for DWL Experiment
  - Control + ADM

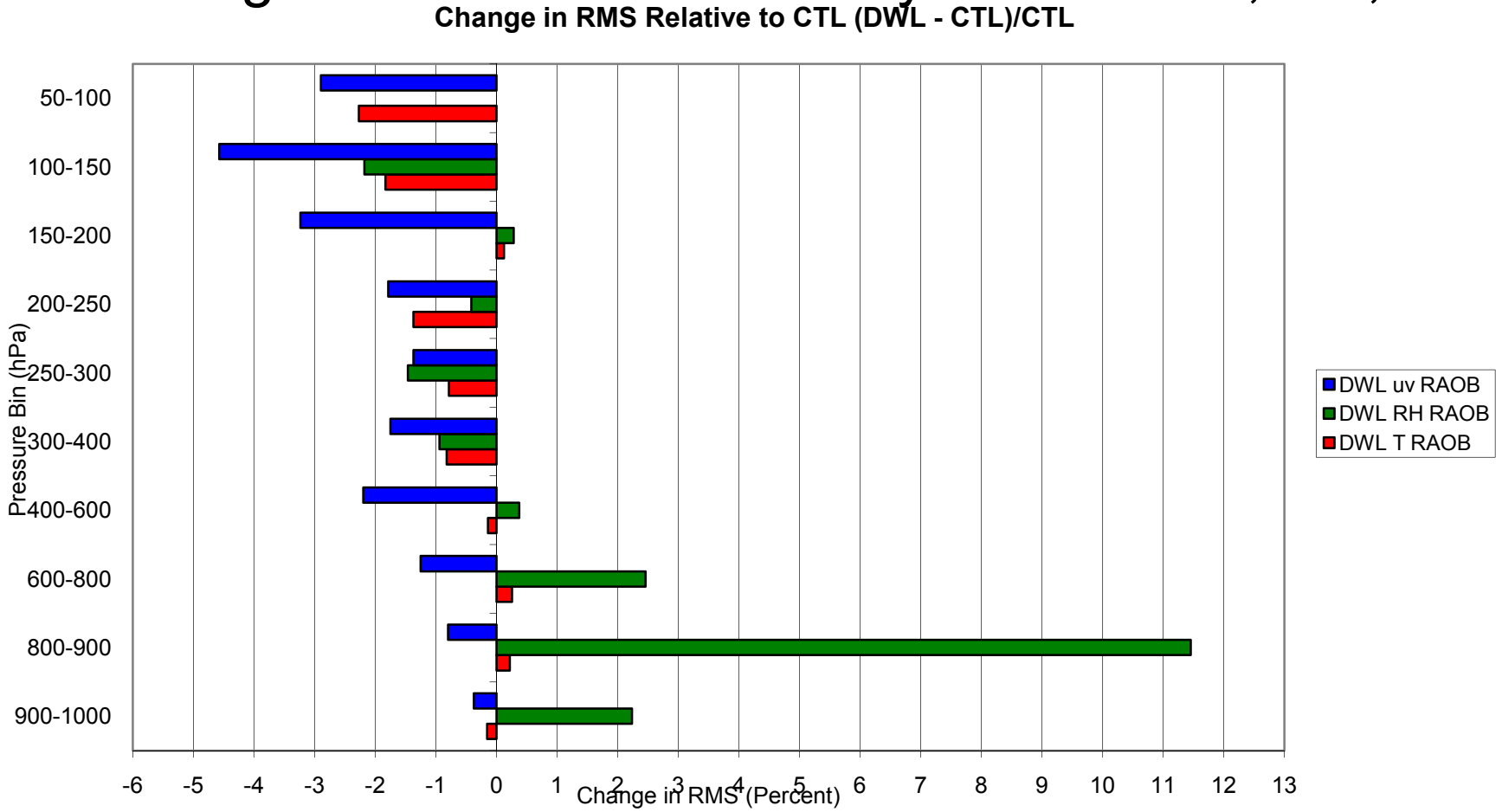
Assimilation Results

- Doppler Wind Lidar O-F RMS vertically



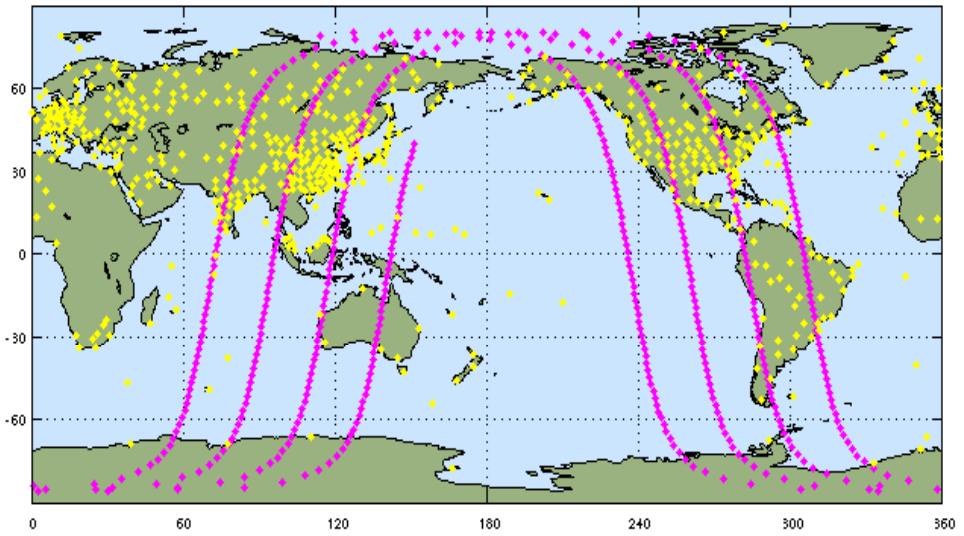
Assimilation Results

- Change in DWL RMS Vertically for RAOB T, RH, and uv



Assimilation Results

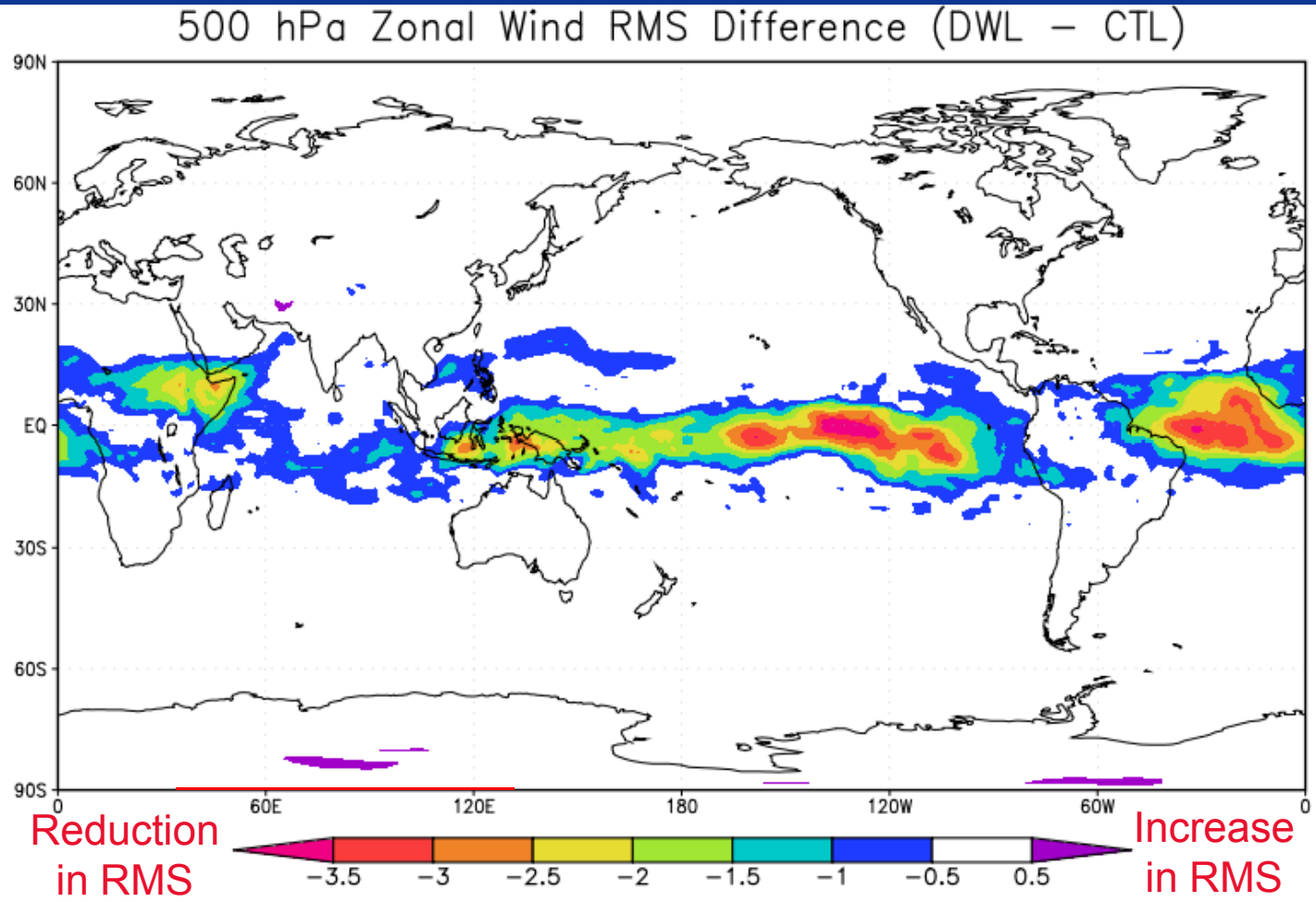
- RAOB observations biased towards Northern Hemisphere midlatitudes
- OSSE framework allows comparison between the analysis and a known truth in analysis space



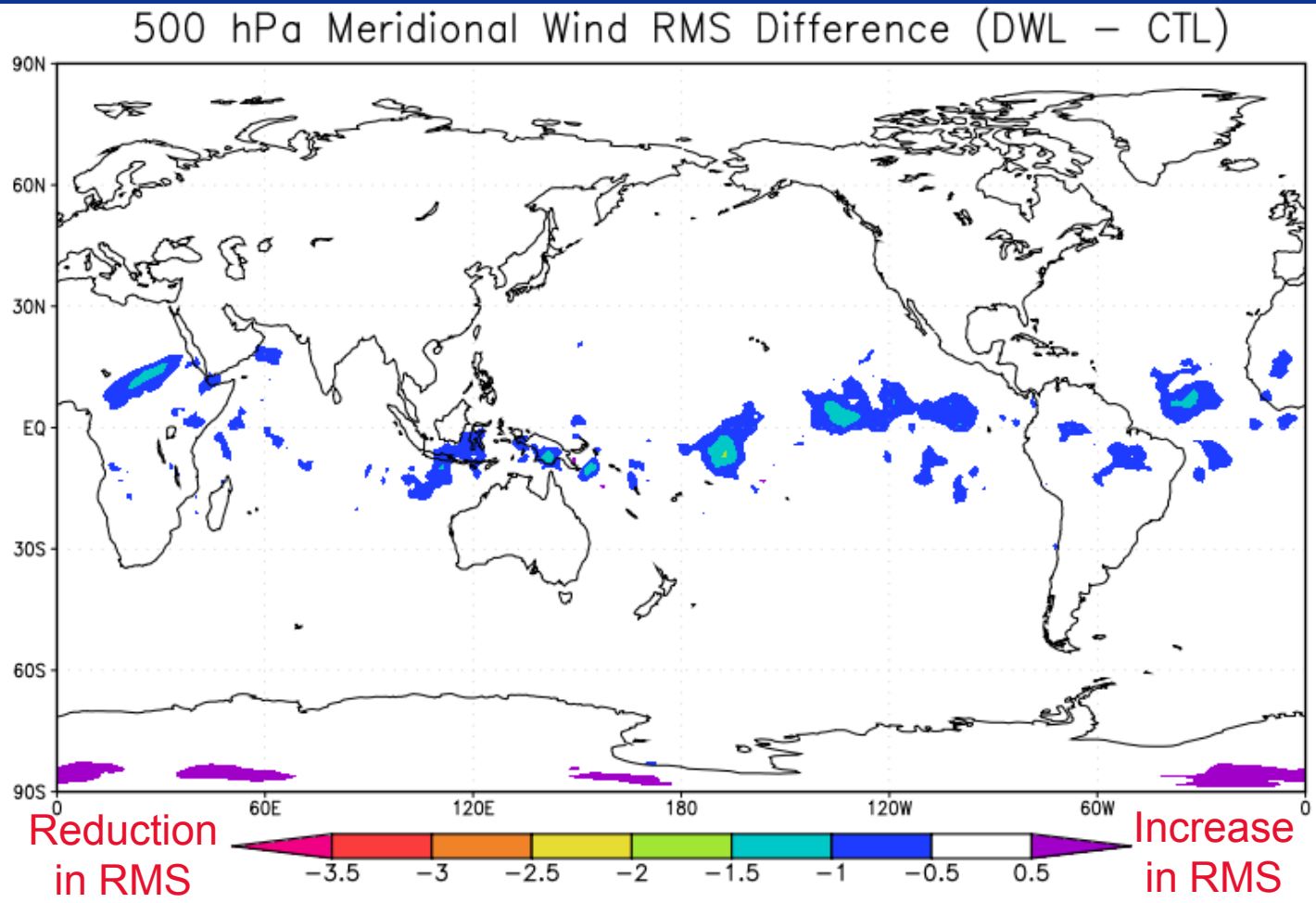
Radiosonde ADM

Observation Locations

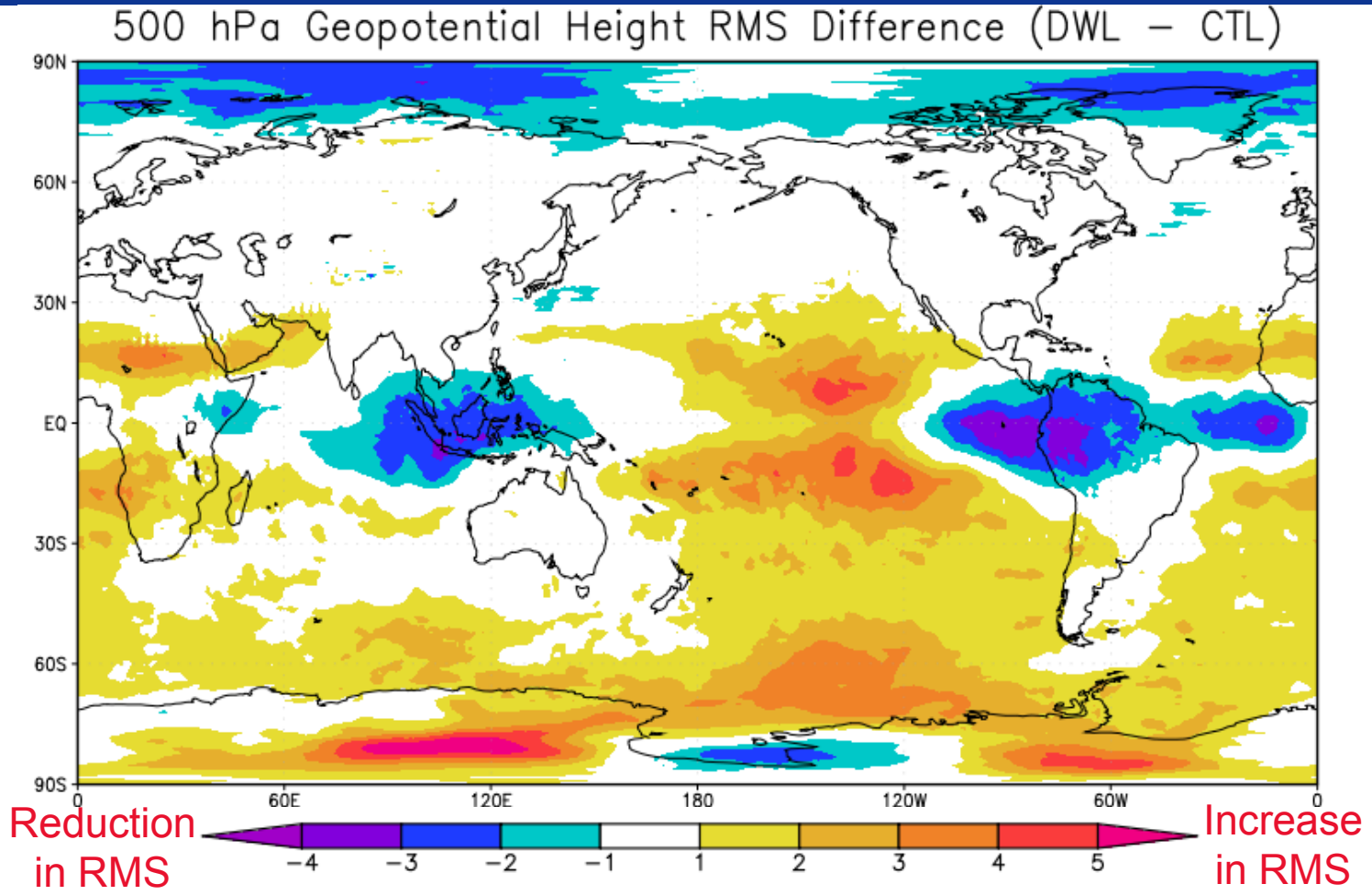
Assimilation Results



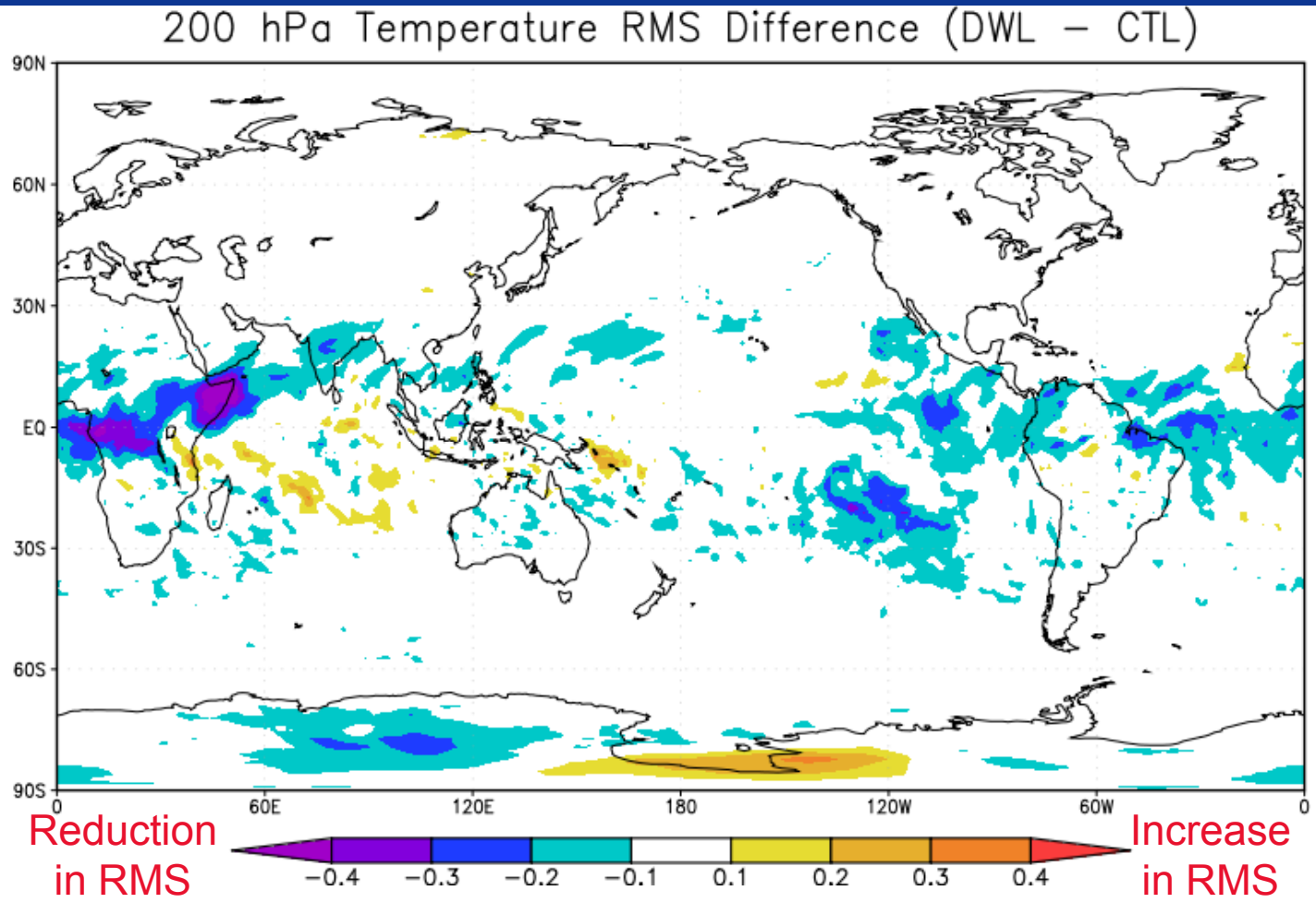
Assimilation Results



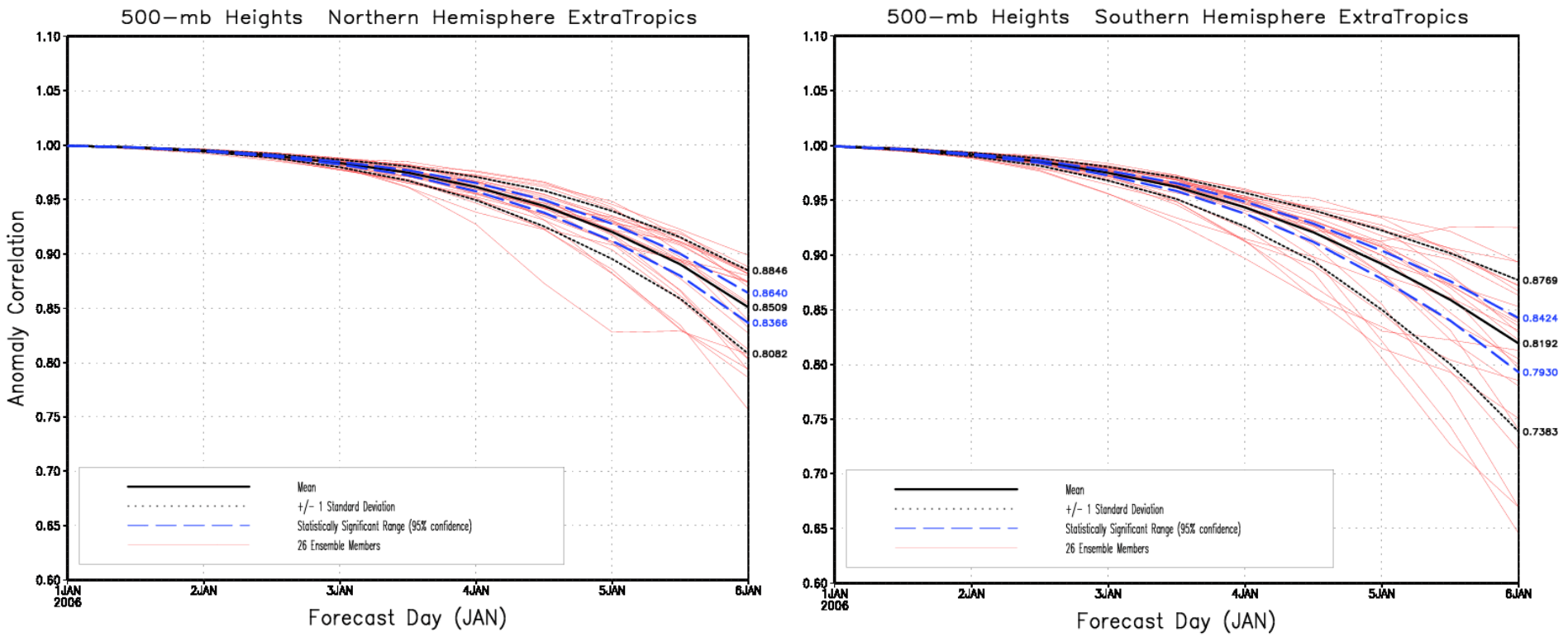
Assimilation Results



Assimilation Results



Impact on Forecast

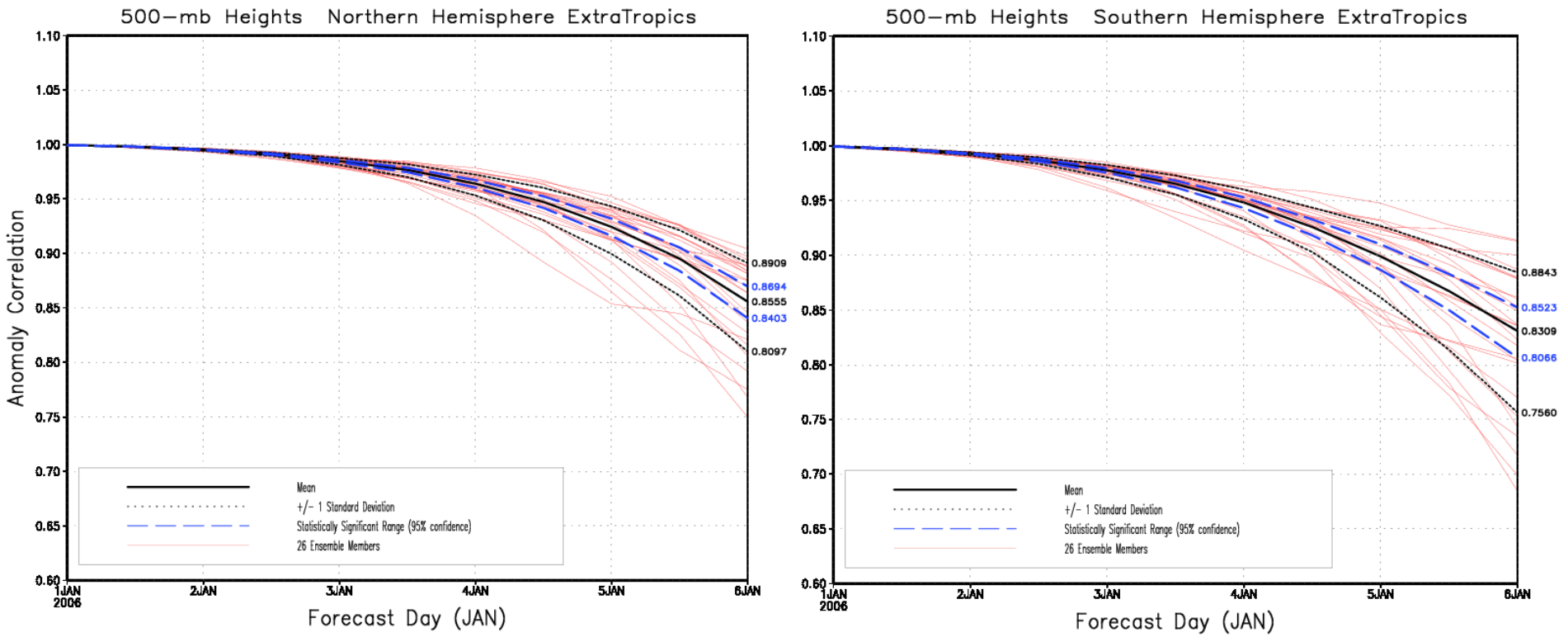


500 hPa Height Anomaly Correlation (CTL)

NH – 0.8509

SH – 0.8192

Impact on Forecast



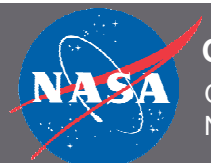
500 hPa Height Anomaly Correlation (DWL)

NH – 0.8555

SH – 0.8301

Conclusions and Future Efforts

- There are known flaws with the current use of ADM data in the OSSE experiment
  - Observations are too ideal (quality & quantity)
  - Representativeness errors are underspecified
- Expand experiment to increase statistical robustness
- ADM Effort readily translates to studies for 3D-Winds decadal survey mission
- Incorporate L2B processing into GSI system
  - Accelerate ADM/future DWL observation usage into operations
  - Joint Center for Satellite Data Assimilation task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